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Lopez

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[54] **LOW IMPEDANCE LOOP ANTENNAS**

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[73] Assignees: **BAE SYSTEMS Aerospace Inc.; Advanced Systems**, both of Greenlawn, N.Y.

[21] Appl. No.: **09/238,568**

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[51] **Int. Cl.**^{7} **H01Q 11/12**

[52] **U.S. Cl.** **343/866**; 343/867; 343/741; 343/742

[58] **Field of Search** 343/866, 867, 343/741, 742, 870, 743, 725, 728; H01Q 11/12

[56] **References Cited**

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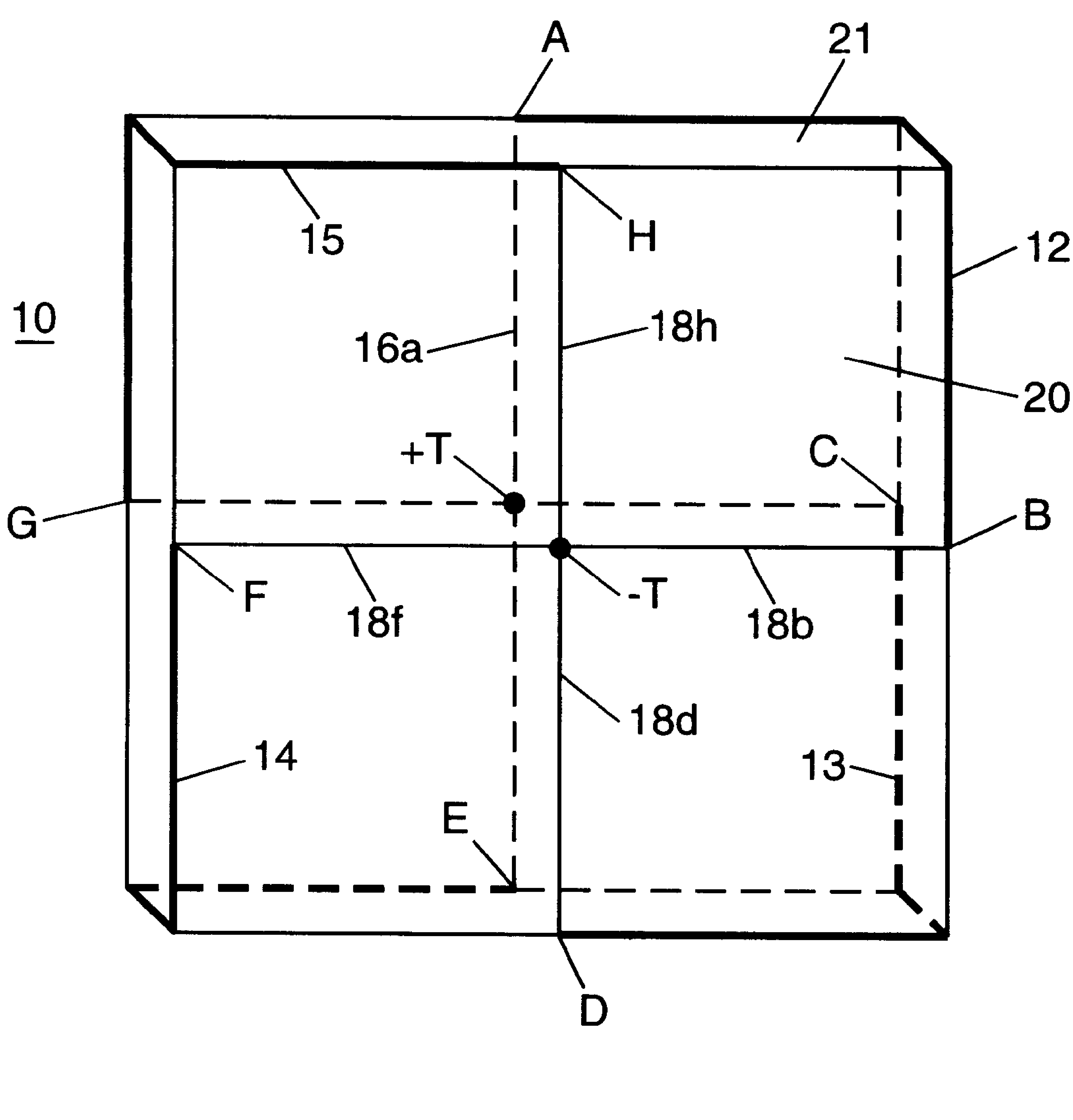
Attorney, Agent, or Firm—Edward A. Onders; Kenneth P. Robinson

[57] **ABSTRACT**

Low impedance loop antennas utilize a loop separated into a plurality of radiating segments fed in parallel. A four point feed loop antenna, including radiating segments **12, 13, 14, 15** had a measured input impedance varying from 1.8 to 5.8 Ohms over a range of 5 to 15 MHz, without excessive radiation Q degradation. An incorporated feed network includes transmission line segments, with conductors on opposite surfaces of a thin substrate, connecting the radiating segments to a centrally mounted coaxial connector for parallel excitation. Operating bandwidth of the loop antenna is determined by the characteristic impedance of the transmission line feed segments. Low impedance loop antennas which are small relative to operating wavelength can be fabricated on a thin flexible substrate for field transport and use. Incorporation of the antenna into a jacket or other clothing enables field use while minimizing restriction of activity of the user.

17 Claims, 5 Drawing Sheets



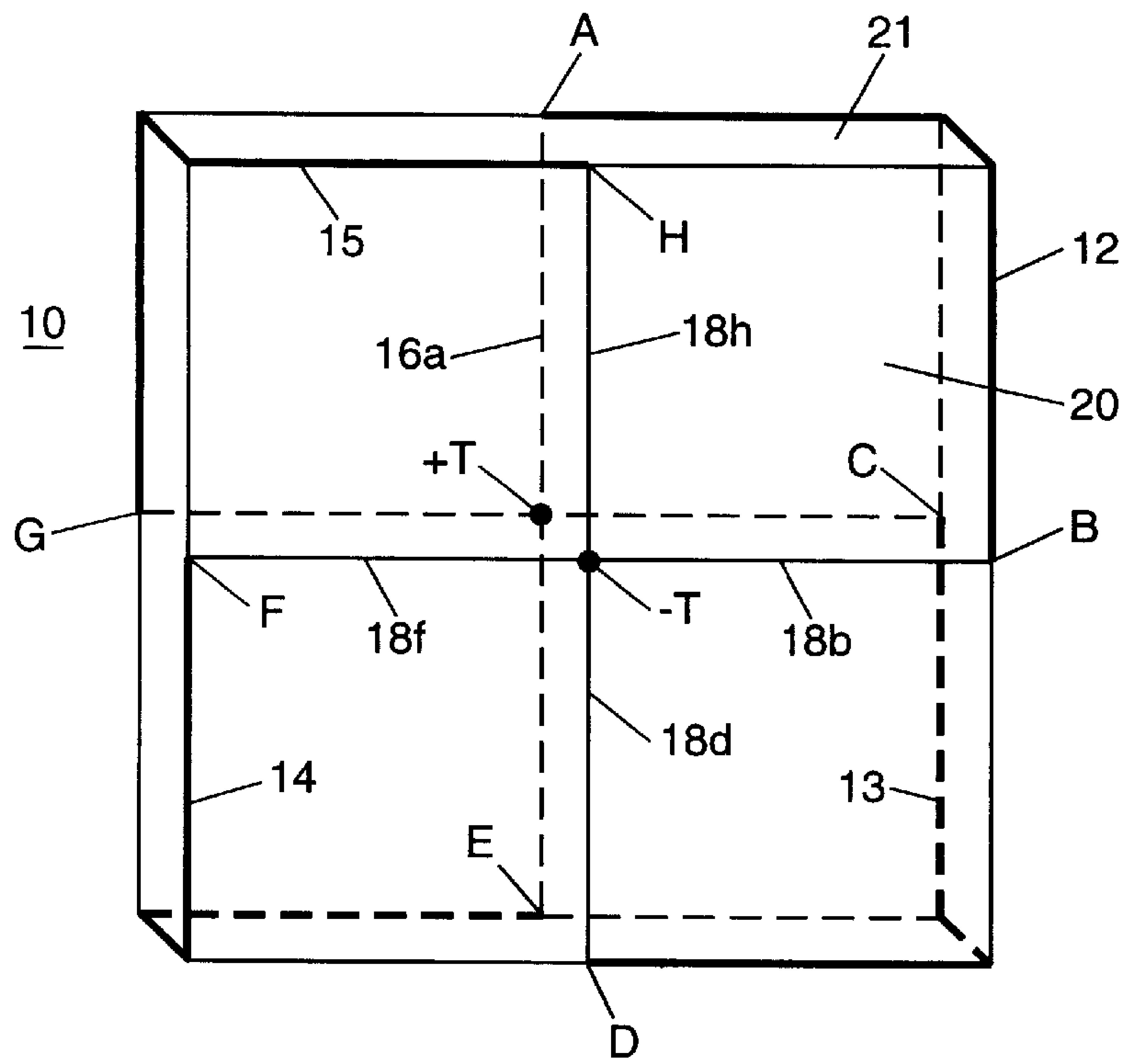
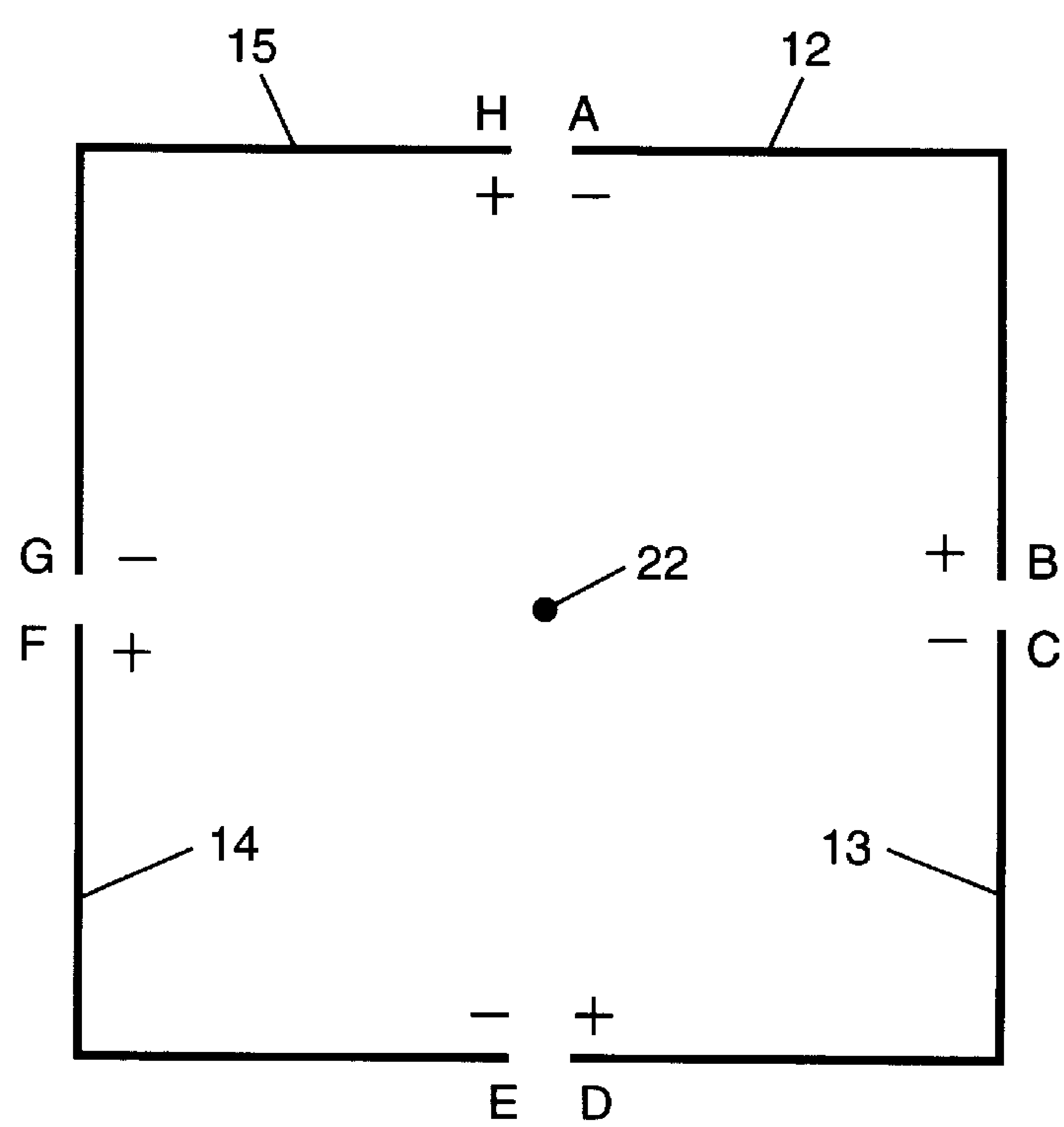

A
21
15
H
12
10
16a
18h
20
+T
C
G
B
F
18f
-T
18b
18d
14
13
E
D

FIG. 1


15
12
H
A
+
–
G
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22
+
B
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+
–
C
14
13
–
+
E
D

FIG. 2

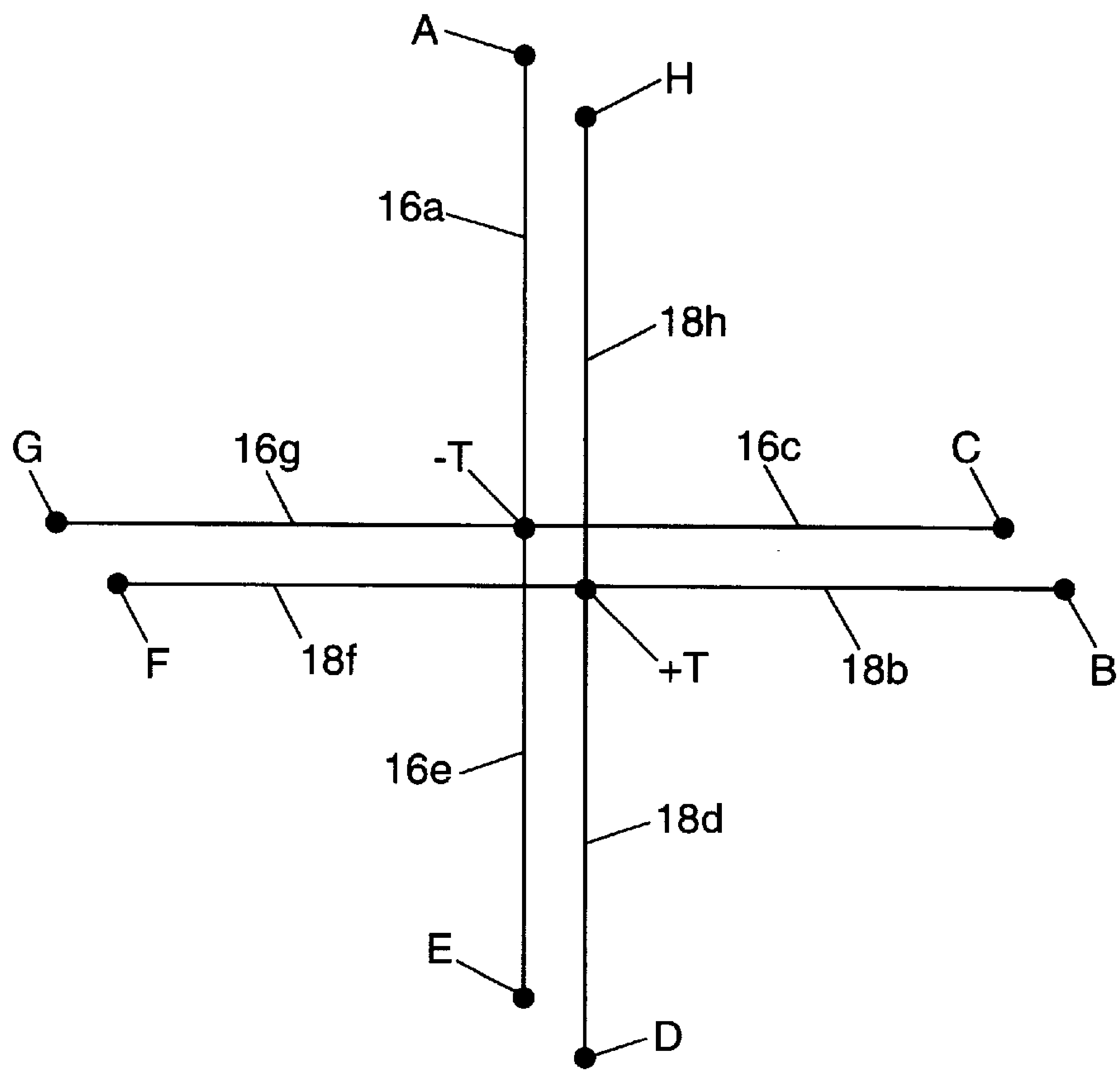


FIG. 3

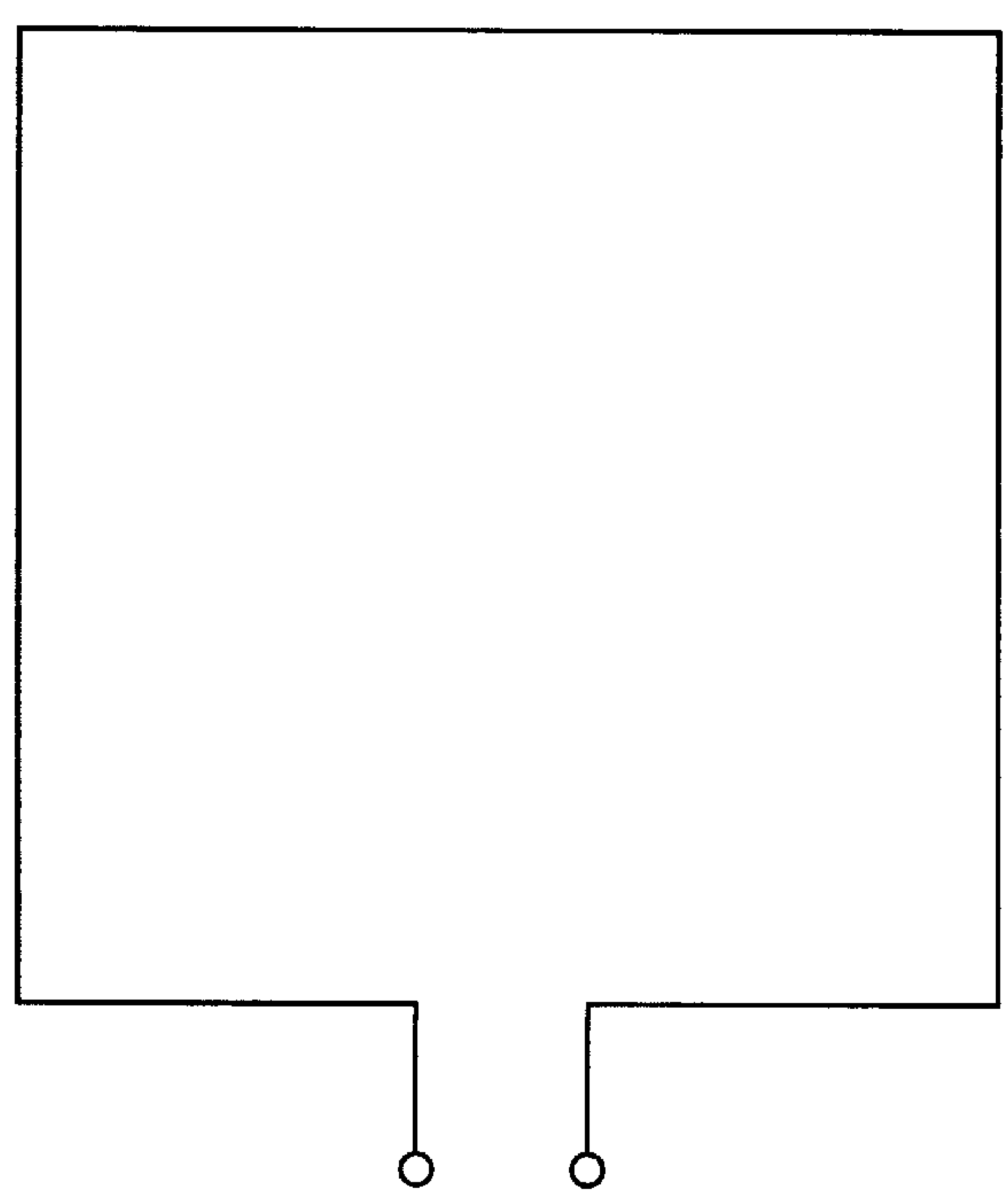


FIG. 4
PRIOR ART

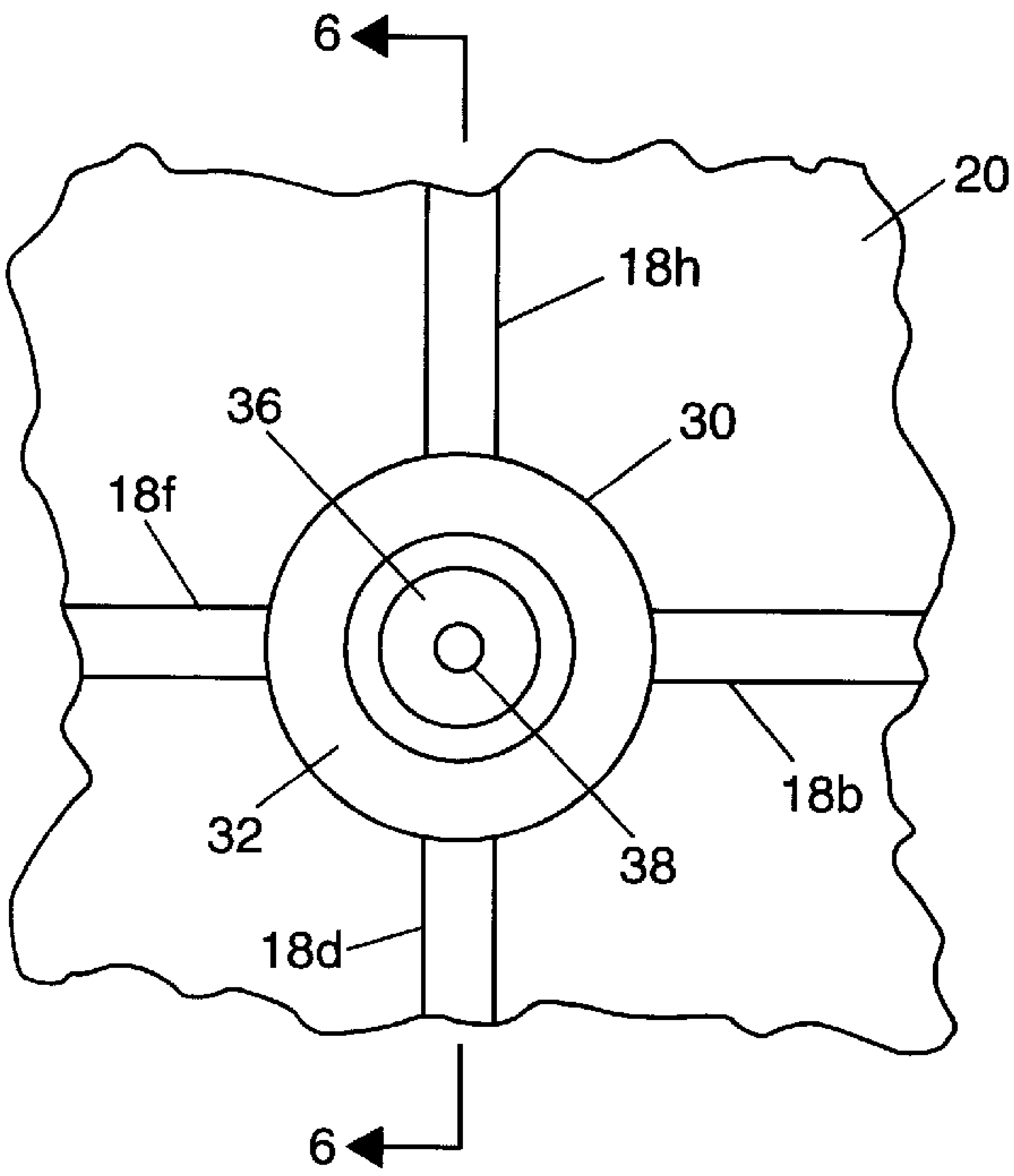


FIG. 5

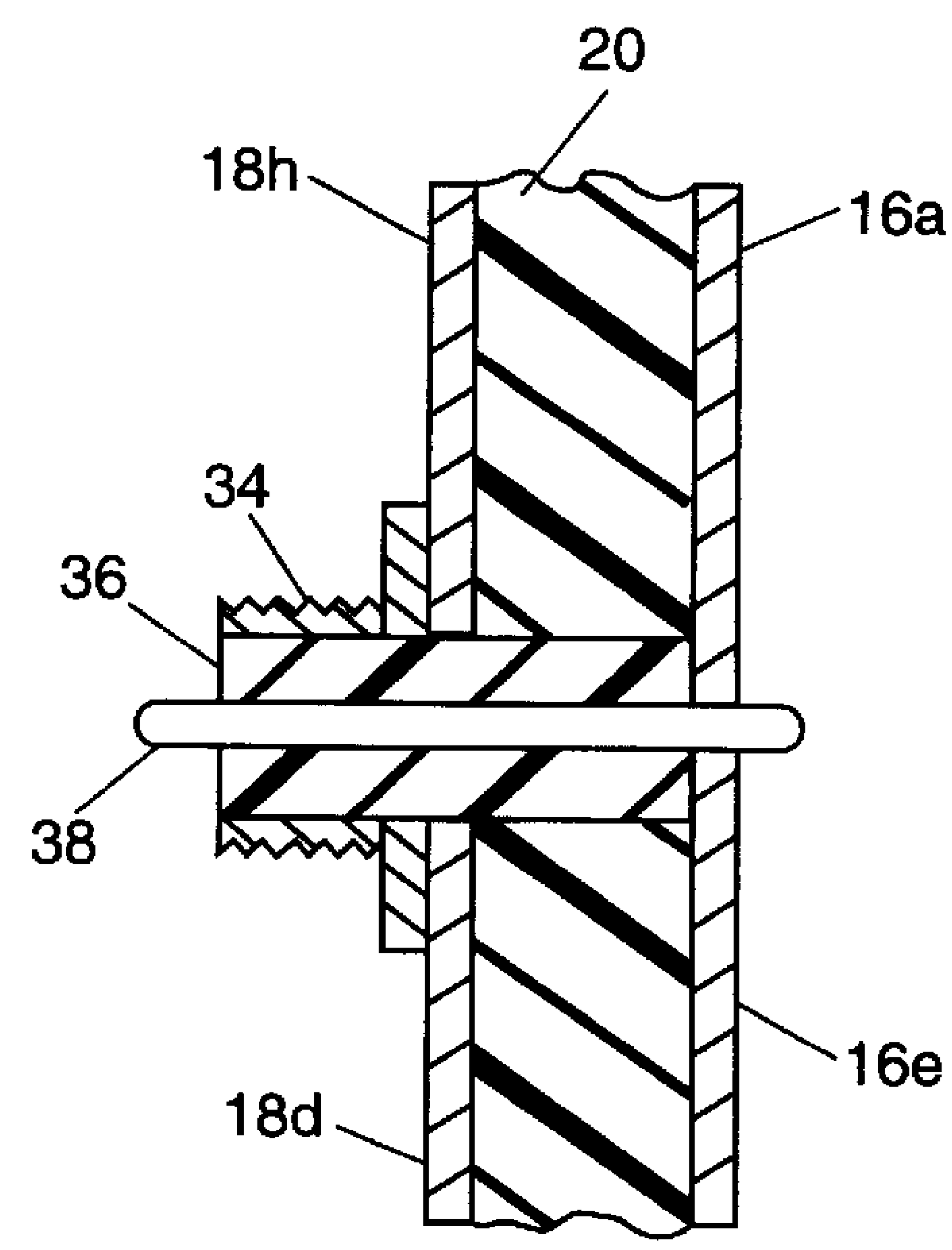


FIG. 6

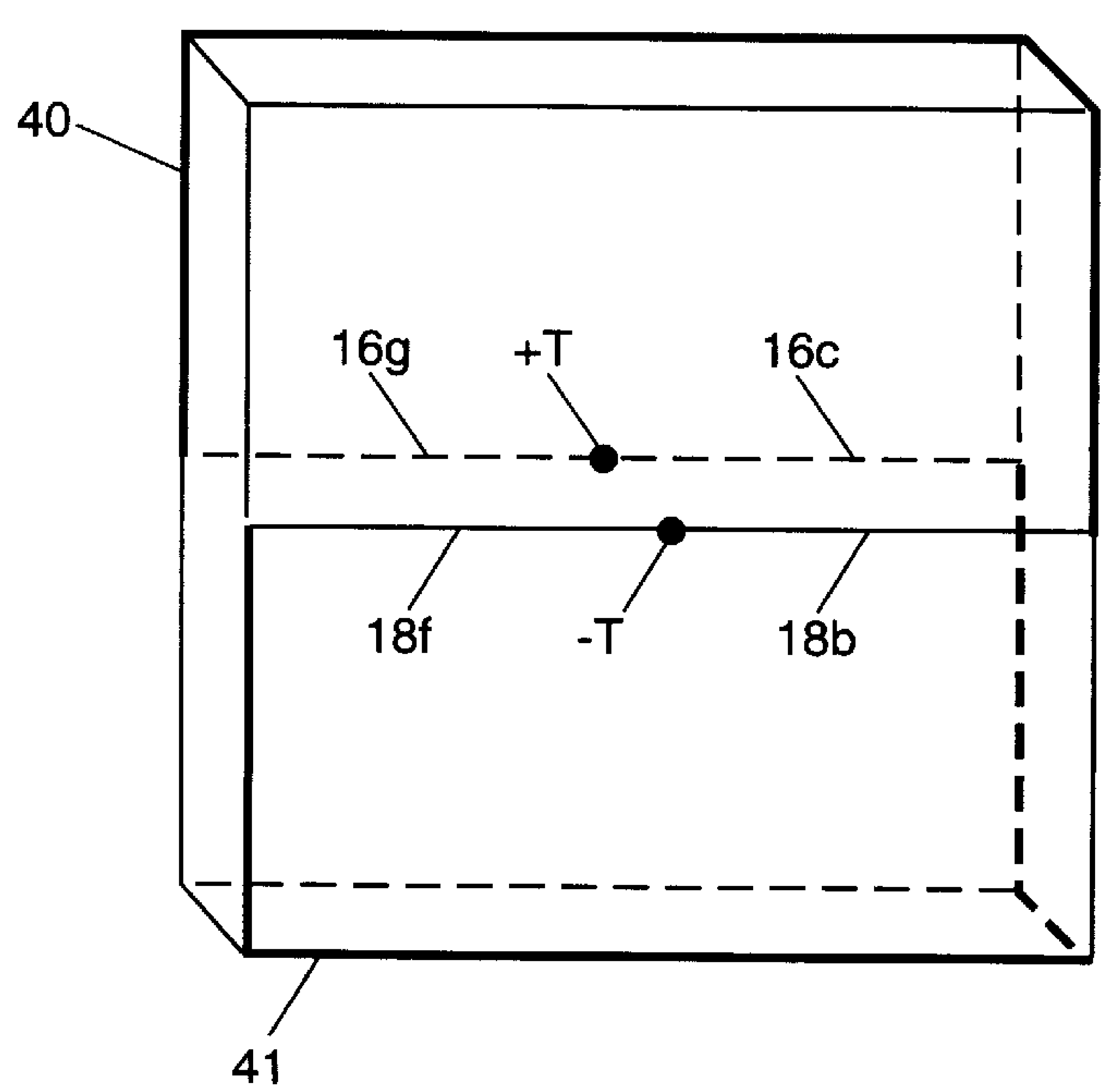


FIG. 7

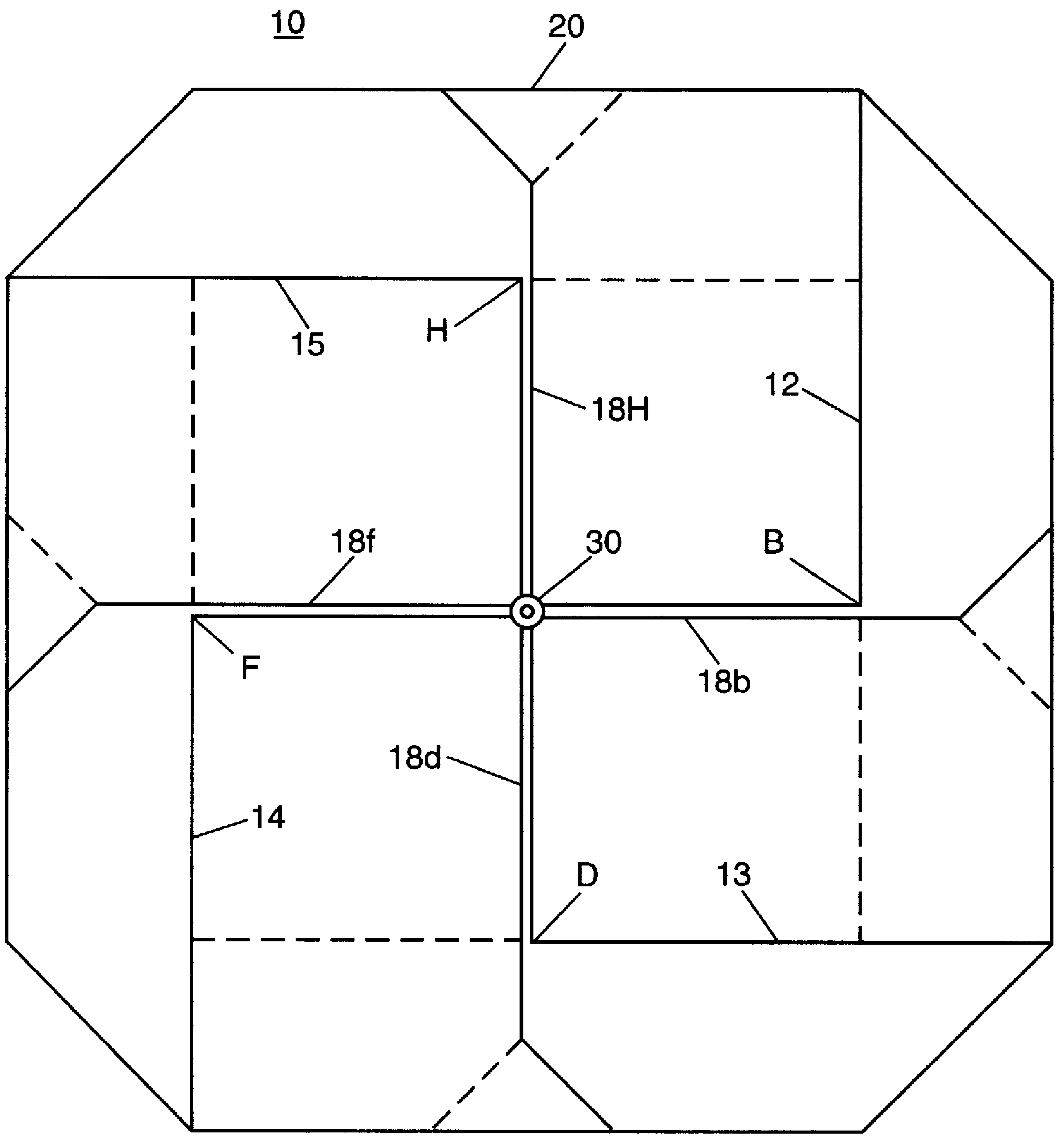
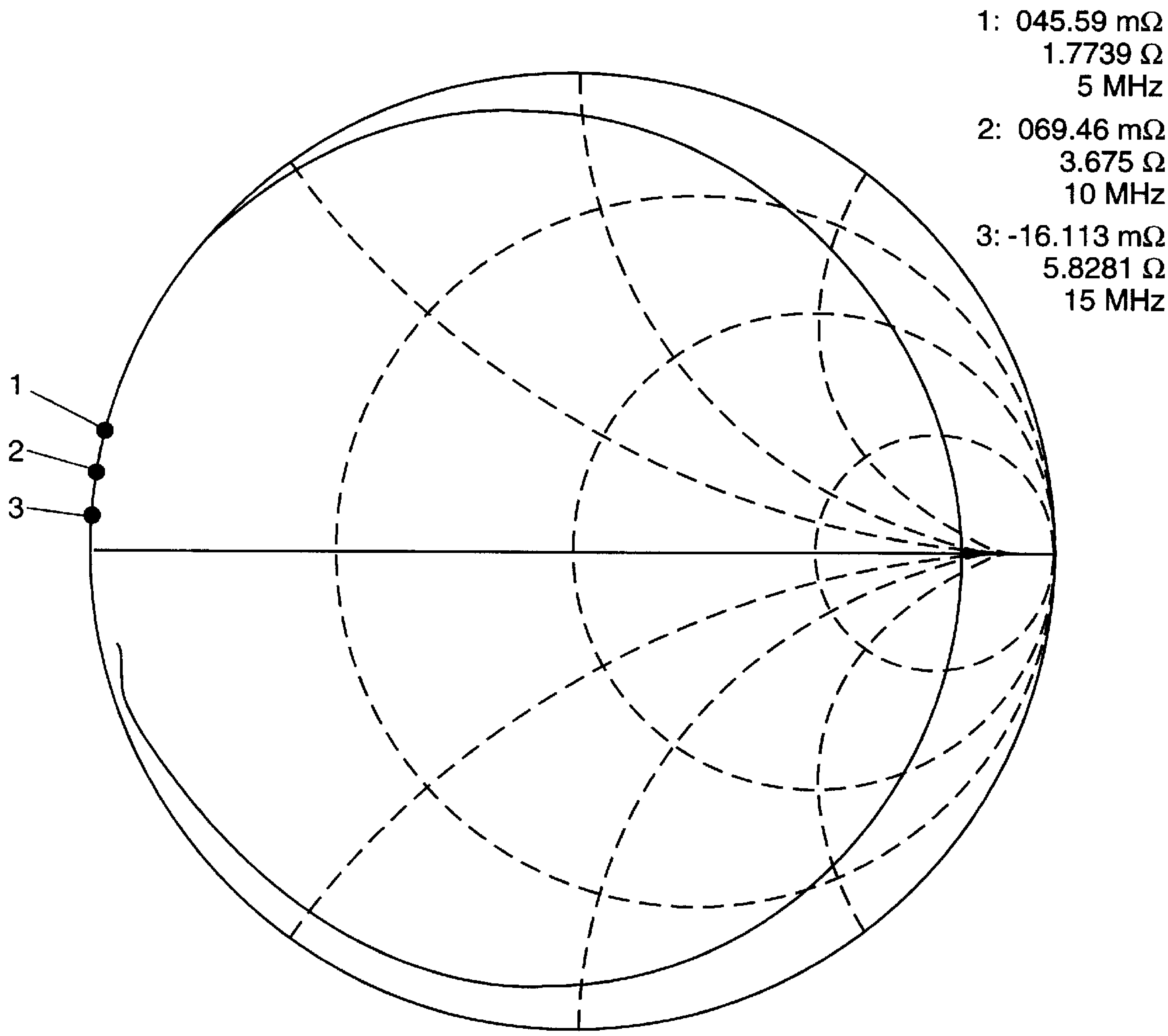


FIG. 8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1.7739 Ω
5 MHz
2: 069.46 mΩ
3.675 Ω
10 MHz
3: -16.113 mΩ
5.8281 Ω
15 MHz
1
2
3

FIG. 9

LOW IMPEDANCE LOOP ANTENNAS

RELATED APPLICATIONS

(Not Applicable)

FEDERALLY SPONSORED RESEARCH

(Not Applicable)

BACKGROUND OF THE INVENTION

This invention relates to antennas and, more particularly to loop antennas having an input impedance which is low relative to prior antennas of this type.

Loop antennas of the general type illustrated in FIG. **4** are well known. For example, a square loop that is 0.5 meters on each side, formed of a conductor of one inch diameter, will have a reactance of about 37 Ohms at a frequency of 5 MHz.

U.S. Pat. No. 5,402,133 issued to J. T. Merenda on Mar. 28, 1995, ("Merenda") describes synthesizer radiating systems capable of providing efficient wideband operation with use of a small loop antenna. The word "small" being used to refer to antenna size relative to wavelength. The disclosure of the Merenda patent is hereby incorporated by reference herein.

In application of antenna systems in accordance with the Merenda patent it is desirable to provide low impedance loop antennas. In particular applications, the 37.3 ohm impedance of the loop antenna referred to above is higher, by a factor of about four, than the impedance level required in order to approach optimal performance in a Merenda antenna system implemented with available circuit devices separate from the antenna.

For use in Merenda antenna systems and other applications for very low impedance antennas it is, therefore, desirable to provide new forms of loop antennas characterized by low impedance without significant degradation of the radiation Q of the antenna system.

Objects of the present invention are to provide new and improved types of loop antennas and such antennas having one or more of the following advantages and characteristics:

- low input impedance, relative to prior loop antennas;
- limited Q degradation, relative to prior loop antennas;
- small size, relative to operating frequency;
- wideband operation;
- incorporated feed network;
- readily accommodated coaxial connector feed;
- flexible, sheet construction;
- economical fabrication; and
- sturdy, high-reliability construction.

SUMMARY OF THE INVENTION

In accordance with the invention, a loop antenna, characterized by low input impedance, includes a radiating element having the general form of a conductive loop about a central point, the loop separated into a plurality of radiating segments each having first and second ends. The antenna further includes first and second input/output terminals, a first conductor configuration coupling the first input/output terminal to the first end of each radiating segment, and a second conductor configuration coupling the second input/output terminal to the second end of each radiating segment.

Also in accordance with the invention, a loop antenna having four radiating sections includes a dielectric substrate having first and second main surfaces and divided into quadrants for reference purposes. A radiating element having the general form of a conductive loop is separated into four radiating segments, with each radiating segment positioned along the edge of one quadrant of the dielectric substrate and having first and second ends. The antenna further includes: first and second input/output terminals; four first conductors supported on the first main surface, each coupling the first input/output terminal to the first end of a different one of the radiating segments; and four second conductors supported on the second main surface, each coupling the second input/output terminal to the second end of a different one of the radiating segments.

For a better understanding of the invention, together with other and further objects, reference is made to the accompanying drawings and the scope of the invention will be pointed out in the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a low impedance loop antenna in accordance with the invention, wherein the loop consists of four parallel-excited radiating segments.

FIG. **2** is a simplified front view of the four radiating segments of the FIG. **1** antenna.

FIG. **3** shows the incorporated feed network of the FIG. **1** antenna, providing parallel excitation of all radiating segments via positive and negative input/output terminals.

FIG. **4** illustrates a prior art type of unitary loop antenna.

FIGS. **5** and **6** are front and side sectional views of a coaxial connector feed port connected to conductors representing the feed network conductors of the FIG. **1** antenna.

FIG. **7** shows a two-segment loop antenna in accordance with the invention in the same drawing format as FIG. **1**.

FIG. **8** is a front view of a FIG. **1** type four-segment loop antenna fabricated on a thin octagon-like substrate with foil-type radiating segments widened to provide reduced capacitive loading.

FIG. **9** is an impedance chart providing test results for the FIG. **8** antenna.

DESCRIPTION OF THE INVENTION

A low impedance loop antenna **10** in accordance with the invention is illustrated in FIG. **1**. FIGS. **2** and **3** represent the radiating segments and feed network portions of the FIG. **1** antenna, respectively.

As illustrated, the FIG. **1** antenna **10** includes a radiating element having the general form of a conductive loop. As represented in simplified form in FIG. **2**, the loop is separated into four radiating segments **12**, **13**, **14**, **15**, each having first and second ends (i.e., respective ends A and B, C and D, E and F, and G and H.) As shown, the radiating segments **12–15** are serially positioned along the peripheral edge of a dielectric substrate **20**.

As illustrated in FIG. **1**, substrate **20** has first (back) and second (front) main surfaces, a finite thickness represented by peripheral edge **21**, and a central point (represented as reference point **22** in FIG. **2**). Substrate **20** may typically be a portion of a thin sheet of insulative material and in particular applications may be either stiff or flexible, for example. For purposes of description and reference, substrate **20** may be considered to be divided into quadrants (four similar reference portions) by the feed network conductors present in FIG. **1**. In other embodiments, substrate **20** may be omitted and the radiating segments and supporting feed network fabricated to provide a self-supporting structure.

The FIG. **1** antenna includes first and second input/output terminals, shown respectively as terminals +T and −T. As will be described below, terminals +T and −T may be connected to the central conductor and outer conductor portions of a coaxial connector to facilitate connection of a coaxial cable for coupling signals to and from the antenna.

As shown the antenna **10** also includes a feed network comprising first and second conductor configurations. In the FIG. **1** embodiment, the first conductor configuration (as represented more particularly in FIG. **3**) includes four first conductors **16***a*, **16***c*, **16***e* and **16***g*, each coupling the first input/output terminal +T to the first end of a different radiating segment (i.e., to first ends A, C, E and G of segments **12**, **13**, **14** and **15**, respectively). The second conductor configuration includes four second conductors **18***b*, **18***d*, **18***f* and **18***h*, respectively coupling the second input/output terminal −T to the second ends B, D, F and H of the respective radiating segments.

In the illustrated embodiment, each of the radiating segments **12–15** is supported along the edge of one quadrant of the substrate **20**, the feed conductors **16***a*, **16***c*, **16***e* and **16***g* are supported on the rear (first) surface of substrate **20**, and the feed conductors **18***b*, **18***d*, **18***f* and **18***h* are supported on the front (second) surface of substrate **20**. As noted, in other embodiments substrate **20** may be omitted and a self supporting structure utilized. With the FIG. **1** embodiment, substrate **20** may be quite thin and formed of any suitable material with individual conductors and radiating segments formed by printed circuit or other techniques and bonded or otherwise supported on the substrate. With individual conductors such as **16***a* and **18***h* superimposed (in opposed alignment) on opposite sides of a substrate, microstrip or other techniques may be employed to provide transmission line sections of appropriate characteristics for feeding the radiating segments. With use of a thin flexible substrate, an antenna such as illustrated in FIG. **1** may be provided in a form which can be rolled or folded to a small size, easily transported, and then opened for use. This enables an antenna which is of relatively small size to be rolled or folded to a smaller size for transport by an individual in preparation for use in the field. To minimize restriction of activity of an individual utilizing the antenna, it may be provided in a flexible form and incorporated into a jacket or other clothing for field use.

Referring now to FIGS. **5** and **6**, there are shown simplified front and side sectional representations of a coaxial connector arrangement for coupling signals to and from the FIG. **1** antenna. While details in particular embodiments can be provided by skilled persons, in FIG. **5** input/output terminal −T has the form of an annular conductor at the junction of conductors **18***b*, **18***d*, **18***f* and **18***h*, including a circular central opening allowing insertion of portions of the coaxial connector **30**. Such annular conductor is covered by and in contact with the circular base portion **32** of the outer shell of conductor **30** and is thus not visible in FIG. **5**. As illustrated in FIG. **6**, the threaded outer conductor portion **34** of the outer shell of coaxial connector **30** encircles an insulative sleeve **36** which supports inner conductor **38**. As represented in FIG. **6**, inner conductor **38** passes through a small central opening in terminal −T at the junction of conductors **16***a*, **16***c*, **16***e* and **16***g* at the back of the substrate **20**. Solder contact may be provided at the back of the substrate, between the first feed conductor configuration and connector center conductor **38**, and at the front of the substrate, between the second feed conductor configuration and the connector outer base portion **32**. In use, a coaxial cable may readily be connected to the antenna via a cable connector mated with connector **30**.

It will now be understood that the FIG. **1** antenna achieves a lowered input impedance based on use of a four point feed effective to provide parallel excitation of the four radiating segments **12–15**. With an understanding of the four segment, four point feed loop antenna of FIG. **1**, it will be appreciated that in use of the invention a loop may be separated into any plurality of radiating elements, as appropriate to meet impedance and other operating characteristics in a particular application. A fundamental characteristic of antennas utilizing the invention is that antenna input impedance is inversely related to the square of the number of radiating segments into which a loop is separated. Thus, for four segments, on a theoretical basis the impedance is reduced to one-sixteenth the impedance of a similar unitary loop (one-segment) prior art antenna (e.g., as shown in FIG. **4**). The impedance of a two-segment loop is correspondingly reduced by a factor of four. In practice, when a multi-segment loop antenna is constructed pursuant to the invention, the measured impedance may differ to some extent from the theoretical value, as is to be expected in implementation of most antenna designs. For the FIG. **8** antenna (discussed below) which was fabricated and tested, measured parameters were closely consistent with the design parameters as computed.

FIG. **7** illustrates a loop antenna wherein the radiating element is separated into two radiating segments **40** and **41**, each having one end connected to terminal +T and a second end connected to terminal −T. The FIG. **7** antenna may include a supporting substrate and coaxial connector as discussed with reference to FIGS. **1** and **6**. A first conductor configuration (conductors **16***c* and **16***g*) and second conductor configuration (conductors **18***b* and **18***f*) connect the first and second ends of radiating segments **40** and **41** to the respective input/output terminals +T and −T, as shown.

In design of antennas using the invention, the effective impedance level and operational bandwidth are dependent upon the impedance of the transmission lines used in the feed network feeding the radiating segments, as well as upon the number of radiating segments. Thus, the conductors of the feed network illustrated in FIG. **3**, which are supported on opposite sides of the substrate **20** of FIG. **1**, comprise transmission line segments connected between the input/output terminals and the individual radiating segments. Through analysis, it was determined that if the transmission line sections are configured to have a characteristic impedance which results in the lowest possible antenna impedance level the operational bandwidth of the antenna will be reduced. Increasing the value of the transmission line impedance is effective to increase the operational bandwidth to approximate that of a prior art single segment, one point feed loop (FIG. **4**) with little resulting degradation in the radiation Q of the antenna. Antenna systems as described in the Merenda patent utilize the loop inductance in the process of modulating the radiated signal. A rule of thumb useful in this regard is that the loop antenna is essentially an inductor up to a frequency that is one-half of the first resonant frequency of the loop. The first resonant frequency occurs when the loop circumference is equal to one-half wavelength. For a square loop 0.5 m. on a side, the first resonant frequency is 74.9 MHz and the maximum operating frequency is 37.5 MHz. Relative to a FIG. **4** single segment loop, having a maximum operating frequency of 37.5 MHz, an antenna reactance at 5 MHz of 28.9 Ohms, and a radiation Q degradation factor of zero or reference value, analysis indicates transmission line impedance affects a FIG. **7** type two segment loop antenna as follows. The two segment antenna design includes a square loop 0.5 m. on a side with a radiating segment strip width of 100 mm. (approximating 2 in. wire diameter). Computed values for that two segment loop with feed transmission lines of different characteristic impedance are as shown in the following table (as compared to the FIG. **4** one segment/one point feed antenna).

Transmission Line Impedance (Ohms)	Maximum Operating Frequency (MHz)	Antenna Reactance at 5 MHz (Ohms)	Radiation Q Degradation Factor at 5 MHz (dB)
Ref., 1-point feed	37.5	28.9	0
14.9	14.0	7.6	0
32.2	20.5	7.7	0.06
58.0	26.5	8.0	0.22
115.6	35.0	8.7	0.59

Thus, for a FIG. **7** type antenna if transmission line sections **16***c*/**18***b* and **16***g*/**18***f* are proportioned to have a characteristic impedance of the order of 115.6 Ohms, wideband operation is indicated.

Based on the foregoing description, pursuant to the invention a low impedance loop antenna may be provided having the property of an input impedance nominally equal to the input impedance of a unitary loop type loop antenna divided by N^2, where N is the number of radiating segments and N is an integral number greater than one. The term "nominally" is used to define an antenna impedance within plus or minus 20 percent of a stated value, in recognition of the fact that measured impedance of an antenna typically varies somewhat from computed theoretical value. A method of providing a low impedance loop antenna having an input impedance nominally equal to $1/N^2$ times the input impedance of a unitary loop type loop antenna includes the steps of:

(a) Providing a radiating element in the form of a conductive loop separated into N radiating segments, where N is an integer greater than one (e.g., 2, 3, 4, etc.).

(b) Providing feed conductors arranged to feed all N radiating segments in parallel (e.g., as in FIG. **3**).

(c) Fabricating the feed conductors in the form of transmission line sections.

(d) Dimensioning the transmission line sections to have a characteristic impedance effective, in combination with the radiating segments, to provide a predetermined antenna operating frequency bandwidth (as discussed in relation to the table above).

(e) Supporting said radiating segments and transmission line sections on the surfaces of a thin dielectric substrate.

As will be appreciated, the foregoing steps are not necessarily included above in successive order, but may be implemented in appropriate order and combination by skilled persons once having an understanding of the invention.

Referring now to FIG. **8**, there is illustrated a four segment, four point feed loop antenna pursuant to the invention which was constructed and tested. The FIG. **8** antenna was constructed using copper foil radiating segments and feed conductor strips adhered to a thin fiberglass sheet, with a center-mounted coaxial conductor. The FIG. **8** antenna is thus an embodiment of the antenna described above with reference to FIGS. **1**, **5** and **6**. Specific design features of the FIG. **8** antenna include widening of the four radiating segments in order to reduce capacitive loading of the loop, and diagonal "clipping" of the corner of each quadrant of the substrate, resulting in a modified octagon shape. Viewing FIG. **8**, with reference to FIG. **1**, it will be seen that only segment end points B, D, F and H and feed network conductors **18***b*, **18***d*, **18***f* and **18***h* are visible in FIG. **8**. The remaining segment end points and conductors **16***a*, **16***c*, **16***e* and **16***g* are on the reverse side of substrate **20**. In this configuration, the first foil portion of segment **12** connected to conductor **18***b* is on the front of the substrate, the foil segment **12** then continues around the diagonal edge portion of substrate **20** and extends to the left on the back surface of the substrate to the not-visible point A where it connects to conductor **16***a*, which is behind conductor **18***h* and not visible in the FIG. **8** view. The remaining radiating segments **13**, **14** and **15** similarly each have a front portion connected to one of conductors **18***d*, **18***f* and **18***g* and continue around on the back surface of the substrate for connection to one of conductors **16***c*, **16***e* and **16***g*, which are not visible in FIG. **8**. An antenna of the type illustrated in FIG. **8** can be fabricated by use of printed circuit or other appropriate techniques. Coaxial connector **30** is positioned at the center of the substrate.

Computed values for the FIG. **8** antenna design of a size 0.5 m. on a side with feed transmission line sections of different characteristic impedance are as shown in the following table. Radiation Q will be quite high, and may be of the order of 200,000.

Transmission Line Impedance (Ohms)	Maximum Operating Frequency (MHz)	Antenna Reactance at 5 MHz (Ohms)	Radiation Q Degradation Factor at 5 MHz (dB)
Ref., 1-point feed	37.5	28.9	0
23.8	30	2.13	0
57.8	45	2.3	0.1
89.4	54	2.73	1.1
126.6	62	3.03	1.5

FIG. **9** provides results recorded during testing of a 0.5 m. antenna fabricated as illustrated in FIG. **8**, using feed network segments having a characteristic impedance of about 20 Ohms. Measured reactive impedance of the four segment, four point feed antenna at different frequencies was: 1.8 Ohms at 5 MHz (FIG. **9**, point **1**), 3.7 Ohms at 10 MHz (point **2**) and 5.8 Ohms at 15 MHz (point **3**). Radiation Q adegradation was minimal, relative to the Q of a FIG. **4** single feed, single segment type loop. The tests thus confirm the capability of antennas constructed in accordance with the invention to provide low antenna impedance with wideband operating characteristics.

While there have been described the currently preferred embodiments of the invention, those skilled in the art will recognize that other and further modifications may be made without departing from the invention and it is intended to claim all modifications and variations as fall within the scope of the invention.

What is claimed is:

1. A loop antenna, characterized by low input impedance, comprising:

a radiating element having the general form of a conductive loop about a central point, said loop separated into a plurality of radiating segments each having first and second ends;

first and second input/output terminals;

a first conductor configuration coupling said first input/output terminal to the first end of each of said radiating segments;

a second conductor configuration coupling said second input/output terminal to the second end of each of said radiating segments; and a dielectric substrate supporting said radiating segments, with said first and second conductor configurations disposed on opposing main surfaces of the substrate.

2. A loop antenna as in claim **1**, wherein said loop is separated into two radiating segments and said first and second conductor configurations each include two conductors arranged to provide parallel excitation of the two radiating segments.

3. A loop antenna as in claim **1**, wherein said loop is separated into four radiating segments and said first and second conductor configurations each include four conductors arranged to provide parallel excitation of the four radiating segments.

4. A loop antenna as in claim **1**, wherein said first and second conductor configurations include transmission line sections coupled from said first and second input/output terminals to respective ends of said radiating segments.

5. A loop antenna as in claim **4**, wherein said transmission line sections are configured to have a characteristic impedance selected to cause said loop antenna to have at least a predetermined operating frequency bandwidth.

6. A loop antenna as in claim **1**, additionally including a coaxial connector connected to said first and second input/output terminals.

7. A loop antenna, characterized by low input impedance, comprising:

a dielectric substrate having first and second main surfaces, a peripheral edge and a central point;

a radiating element having the general form of a conductive loop separated into a plurality of radiating segments serially positioned along said peripheral edge, each radiating segment having first and second ends;

first and second input/output terminals;

a first conductor configuration supported on said first main surface and coupling said first input/output terminal to the first end of each of said radiating segments; and

a second conductor configuration supported on said second main surface and coupling said second input/output terminal to the second end of each of said radiating segments.

8. A loop antenna as in claim **7**, additionally including a coaxial connector connected to said first and second input/output terminals.

9. A loop antenna as in claim **7**, wherein said loop is separated into two radiating segments and said first and second conductor configurations each include two conductors arranged to provide parallel excitation of the two radiating segments.

10. A loop antenna as in claim **7**, wherein said loop is separated into four radiating segments and said first and second conductor configurations each include four conductors arranged to provide parallel excitation of the four radiating segments.

11. A loop antenna as in claim **7**, wherein said first and second conductor configurations include transmission line sections coupled from said first and second input/output terminals to respective ends of said radiating segments.

12. A loop antenna as in claim **7**, wherein portions of said first and second conductor configurations are in opposed alignment on opposite sides of said substrate to provide transmission line sections of predetermined characteristic impedance connected to said radiation segments.

13. A loop antenna as in claim **12**, wherein said transmission line sections are configured to have a characteristic impedance selected to cause said loop antenna to have at least a minimum operating frequency bandwidth.

14. A loop antenna, characterized by low input impedance, comprising:

a dielectric substrate having first and second main surfaces and divided into quadrants for reference purposes;

a radiating element having the general form of a conductive loop separated into four radiating segments, each radiating segment positioned along the edge of one quadrant of said dielectric substrate and having first and second ends;

first and second input/output terminals;

four first conductors supported on said first main surface, each coupling said first input/output terminal to the first end of a different one of said radiating segments; and

four second conductors supported on said second main surface, each coupling said second input/output terminal to the second end of a different one of said radiating segments.

15. A loop antenna as in claim **14**, additionally including a coaxial connector connected to said first and second input/output terminals.

16. A loop antenna as in claim **14**, wherein individual conductors of said first four conductors are in opposed alignment to individual conductors of said second four conductors on opposite main surfaces of said substrate, to provide transmission line sections of predetermined characteristic impedance connected to said radiating segments.

17. A loop antenna as in claim **14**, wherein said substrate is formed of thin flexible insulative material.

* * * * *